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Robert E. Kahn
ARPA-IPT

PACKET RADIO ISSUES - I

Five basic packet radio issues are discussed in this memorandum. For each issue, a specific recommendation is put forth as to the appropriate initial design objective. Included are: local area selection, repeaters vs. stations, packet size, slotting or packet sensing, and multiple frequencies or not.

The discussion here is not intended to be extensive or conclusive; rather its purpose is to highlight the issues and to lay them on the table.

1. Selection of the local area - Radio propagation in a flat open area with line of sight is far less "cluttered" than that in a downtown urban area containing many tall buildings and significantly greater multipath. Consequently, the design problems for the downtown urban area appear far more difficult to solve. The capability and effectiveness of a packet radio system can be measured in many convenient environments. We should not overreach ourselves by attempting to design and build an initial packet radio system for use in the worst of environments rather than a good one. A logical design choice is a residential urban area, possibly one with nearby elevated

areas. Several candidates come to mind instantly...

For this environment, an initial spacing of 5-25 miles per repeater is a useful range for system evaluation. We may eventually need to design for a different spacing for technical or economic reasons.

2. Repeaters vs. Stations - The notion of a station is central to radio broadcasting. What is not central, however, is the notion of broadcasting to the station rather than away from it. In either event the introduction of repeaters is useful to

(1) extend the station's range outward - the usual case and

(2) to extend the user's range inward - a newly introduced case.

The view is taken here that the repeater is introduced principally to extend the user's range.* A distant user with a low powered hand held terminal can be located far enough from a high powered, large antenna station to hear the station but not be heard by it.

A key question? If repeaters are needed to relay user traffic to the station, why should the station have more power than a repeater. Moreover, why shouldn't a station be a

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* For the record, we also note here the utility of repeaters to extend the stations range around natural or man made obstacles.

repeater. A possible advantage with centralized routing and traffic control is to reduce the loading of repeaters close to the station. But this only affects the half of the traffic flowing away from the station and only if the close-in repeaters can be deselected in the broadcast. A second possible reason for a high station power is to allow repeater clock synchronization from a single broadcast pilot. This is probably unreliable for a wide deployment of repeaters as well as unnecessary. Comsat acquires carrier and bit synchronization in 120 bit times on a spade channel.

I propose we aim for a decentralized system of repeaters without "stations". They should be programmable. Selected repeaters may subsequently be designated for use as network "interconnection points". These repeaters may later need to be augmented (e.g., with more storage capacity) to perform additional functions, but they need not require substantial increases in power or broadcast capability.

3. Packet Size - The packet radio system, in distinction to the ARPANET, must work efficiently with short packets. They may be a substantial, if not overwhelming, portion of the overall radio traffic. Most hand held terminals will probably transmit packets of length 512 bits and below. However, the system

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should be able to support packets that contain up to 1000 bits of data for compatibility and convenient interconnection with the ARPANET.

The nominal 1000 bit packet size of the ARPANET appears not well suited to hand held terminals. Roberts (SJCC 72) estimated a terminal's single character packet size at 64 bits and a repeater's single character packet size at 144 bits. Speech-like signals will probably need a packet size of about 0.1 seconds buffering plus overhead. For a 3600 bit/second source, this quantity is about 512 bits/packet including overhead. For a design objective, the recommendation is that the packet radio system should efficiently handle packets of length as short as 256 (=250) bits.

4. Packet sensing or slotting - The "factor of two" advantage achieved by the slotted ALOHA system over the unslotted ALOHA, suggests that a slotted packet radio system should also be more efficient than an "unslotted" one. By an unslotted system we mean one in which packets may be "launched" at any point in time with no attempt made to resolve conflicts ahead of time. However, due to asynchrony of packet arrivals and the variable length of packets, more efficient use of the radio

spectrum will be achieved if the slotting can be adjusted to fit closely the size of each packet and its earliest possible non-conflicting "launch" time. This technique requires that a packet sensing method be introduced to delimit the beginning and end of packets already launched and that no packets be discharged by a terminal or repeater when packet interference will obviously occur. Carrier detection is an example of one such method of packet sensing.

Carrier detection is inefficient for either very short packets or high bandwidth circuits. For a 250 bit packet, a 100 kilobit/sec data rate and a 10 mile repeater spacing the system is close to the edge of unacceptability. It takes 20 mi x 5.5 us /mi=110 us to sense that a carrier has been turned on or off. If we delay the start of carrier by some multiple of 110 us once carrier off is detected, (say 1-10 of these intervals, with random delay) we can achieve an ALOHA competition over say 10 slots when two or more packets are simultaneously ready for launching, waiting for carrier off to to occur. We obtain a built-in inefficiency of .55(.55+2.5) = 17% at 100 kilobits/sec due to the average 5 slot delay. At 1.544 Megabits/sec the inefficiency is increased to about 75%.

other things being equal. In this latter range, carrier detection is unsuitable for packet sensing.

As we indicate below, there is urgent reason for a repeater to know when to switch frequencies. This undoubtedly requires high level synchronization of repeaters. If packet sensing is useful at all, it will most likely be in the overall contex of a synchronous slotted system. The recommendation is that we consider a synchronous slotted system for the initial design.

5. Single vs. Multiple Frequencies - The requirement to obtain full system bandwidth at a given mobile terminal leads to the immediate conclusion that at least four different frequencies are needed in the system. To the extent that the four color problem is present here five or more may be required. For economy, we assume the hand terminal transmits and receives on a single frequency. Other mobile terminals may use separate transmit and receive frequencies to obtain higher bandwidth.

Consider a terminal transmitting at the rate of one packet per slot in a synchronous slotted system. Each packet proceeds down a chain of repeaters to its destination, in this case, assumed to be at least four repeaters distant. The first four repeaters, the terminal and a sequence of frequencies

used are shown in Figure 1. The terminal transmits on a single frequency f_0. The repeaters use the frequencies f_1, f_2, f_3, to communicate.

It is observed from the figure that once the first repeater A receives a packet it cannot transmit it in the next slot at frequency f_0 or the terminal transmission will be interferred with. It is transmitted at frequency f_1 to repeater B. Repeater B can transmit it to C using frequency f_1 if it chooses, but repeater A must now use frequency f_2 (or f_3) to avoid interference from B. Similarly repeater C can use f_1 to transmit the packet, but repeater B must use, say, f_2 to avoid having its transmitted signal interferred with, and furthermore repeater A must not use either f_2 or f_1. It uses f_3 to avoid inteferring with the radiation of the immediate neighbor or the neighbor's neighbor.

All the neighbors of a repeater and their neighbors are thus prohibited from using a frequency that it has selected for use in a given slot. This constitutes extremely inefficient use of overall system capacity. Steerable antennas for repeaters must be included in our initial design consideration, but hand held terminals should contain simple omni-directional antennnas.